

**June 1999 Progress Report for:  
Aircraft Radiation and Aerosol Measurements Near Hawaii:  
Satellite Validation At the Moby Buoy and the HOTS Site.**

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Aircraft measurements are being carried out over the MOBY (Marine Optical Buoy) and the HOT (Hawaii Ocean Time-Series) sites near Hawaii to test/validate EOS-AM1 satellite algorithms. The aircraft measurements include a suite of innovative radiation and aerosol measurements, which determine the aerosol optical properties and their radiative effects. All of the measurements carried out will be submitted to the NASA SeaBass archive for use by diverse ocean optics investigators within 2-4 months after measurements. The calibrated data sets, and data plots, are also placed on our web page (<http://www.soest.hawaii.edu/porter>) where they can be download.

The various instruments used are mounted on dedicated aircraft doors and are installed on the light aircraft prior to flight. Removing the original aircraft door and replacing them with our instrumented doors takes approximately 30 min. This approach requires little or no modification to the plane and could be used anywhere around the world provided the proper plane can be found. We use a Piper Seneca aircraft, which is fairly common throughout the world. The Seneca plane can climb up to 16,500 feet (~5.5 km) allowing us to climb well above the trade wind inversion (~2.1 km) over Hawaii. Although we will not fly for long durations at these heights, an oxygen tank has been purchased and is used for the pilot and crew when high altitude flights are carried out. The plane has six seats and the center two seats are removed for installation of the scientific equipment. As this plane is routinely used for training, the FAA must first approve any modifications. In the front door we have installed an aerosol inlet and exhaust venturi. In the back two doors we have installed the radiation equipment.

During the month of May three flights were carried out (May, 9, 11, 29, 1999). The flights were coordinated to fly over the Moana Wave RV during the monthly HOT (Hawaii Ocean Time-Series) cruises. The HOT measurements are made at a site ~100 km north of Oahu where chemical and biological measurement have been made for more than a decade. As part of the SIMBIOS program, in water and above water optical measurements are being made on each cruise. Flights over the MOBY are planned for late July to coordinate with ship cruises to that site.

Aircraft flights are designed to fly over the ship or buoy at altitude for 20 minutes, then descend at the time of the satellite overpass and make additional low level measurements for 20 more minutes. The high level and low level measurements are designed to cover 4-6 square km allowing us to obtain a larger statistical sample, which is representative of the area seen by the satellite. The high and low level flight tracks are flown along the satellite azimuth viewing angle (and at 180 degrees to it) in order to have the same viewing angle as the satellite for our scanning radiometer (described below). The aircraft descends in a spiral over the ship or buoy. The descent takes 10-15 minutes depending on altitude which allows for measurements during the descent and protects the engine. Figure 1 (left panel) shows an image of the Moana Wave RV as we descended on the May 9, 1999 flight. The figure 1, right panel, is an image of a thin layer of pollution seen at 2-3 km. This air pollution is most likely from long-range transport and the frequency; concentration and optical properties of this large-scale aerosol are of concern for satellite retrievals and climate change issues. The HAT (Hawaii Aircraft Time-Series) measurements we are performing will help to define and better model their properties.



Figure 1. An image of the Moana Wave taken on HOT cruise 105 (May 9, 1999). The right panel image shows a weak pollution layer found on this flight above the ship near 3.3 km altitude. Notice the near perfect cloud free conditions.

### **AEROSOL OPTICAL DEPTHS**

Aerosol optical depths measurements are made on each flight using a hand held MicroTops sun photometer. Aerosol optical depth measurements are made at 440, 500, 675 and 870 nm. An additional channel is used to derive water vapor at 935 nm. Pointing the sun photometer at the sun from a moving platform is difficult and requires careful error screening (Porter et al., 1999). This has been applied to the data and preliminary examples are given in Figure 2 and 3. It can be seen that above the inversion the column-integrated water vapor and the aerosol optical depth are low while below the inversion they increase as expected. The water vapor measurements are fairly typical of trade wind days with suppressed cloud activity. Similar MicroTops water vapor and aerosol measurements have been collected on the Moana Wave each month as part of the SIMBIOS effort for the past year (see <http://www.soest.hawaii.edu/porter/simbios.htm>). The MicroTops sunphotometer used on the aircraft is calibrated at the Mauna Loa Observatory and by the SIMBIOS effort (linked to the Aeronet network). Currently the unit has drifted from acceptable calibration and a calibration effort is planned for late June.

### **SCANNING UPWELLING RADIANCE**

A scanning radiance sensor has been built into the aircraft door and is working well. The system uses a fiber optic cable and collection optics to bring light to a spectrometer which covers the range from 380 to 1060 nm with ~1800 channels and ~1 nm FWHM. The sensor field of view is ~2.5 degrees and scans from 0 to 60 degrees nadir. The scanner position is determined with an absolute position encoder

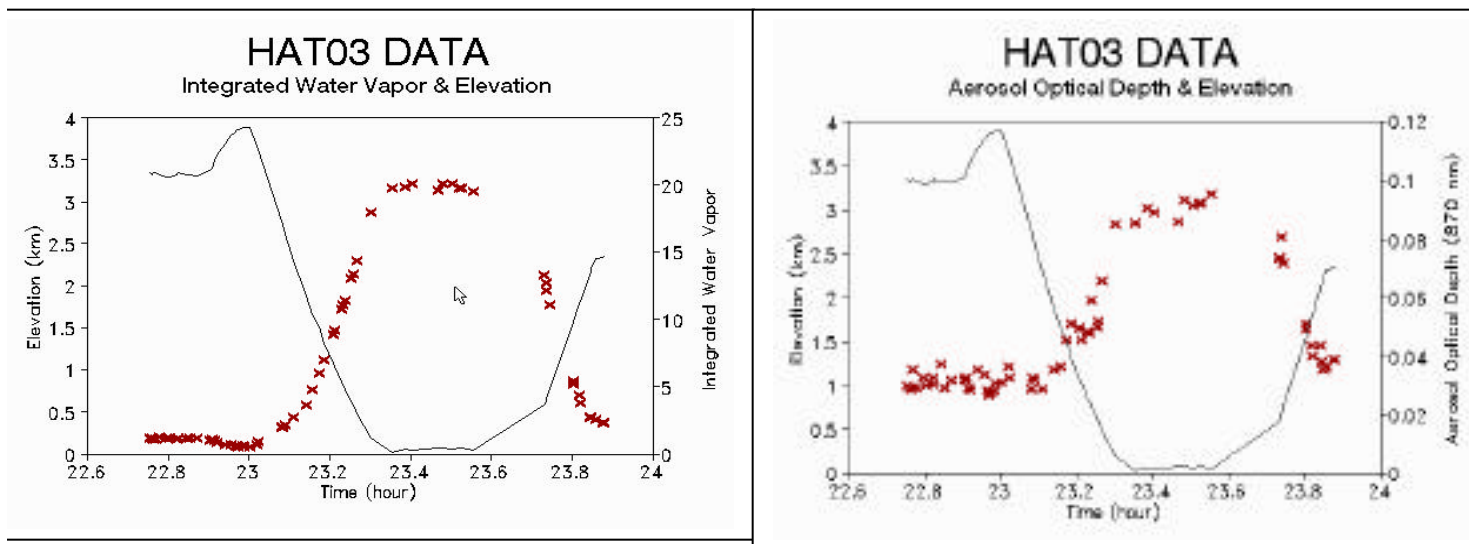


Figure 2. Left panel shows integrated water vapor above the plane measured with a hand held MicroTops sun photometer. These HAT01 (Hawaii Aircraft Time-Series) measurements were taken on May 29, 1999. The thin line shows the aircraft altitude and the dots show the integrated water vapor above the plane. Right panel shown aerosol optical depths at 870 nm collected on HAT01 (May 9, 1998) and HAT03 (May 28, 1999) flights. The values shown here are preliminary. Final calibration will be carried out in June-July 1999.

to better than 0.1 degrees. The spectro-photometer measurements are auto scaling to ensure good signal to noise without saturation. Radiometric calibration is obtained with a NIST traceable Optronics integrating sphere and additional comparisons were recently made at the MOBY calibration facility. Good aircraft measurements were made on the May 11 and May 29 1999 flights. We have just completed wavelength calibration and will be within 0.4 nm wavelength accuracy. Intensity calibration is now being carried out. Once these calibration efforts have been completed, the aircraft attitude will be used to calculate the azimuth and zenith angles. These data are now being processed for recent flights.

## DOWNWELLING AND UPWELLING FLUX

Downwelling and upwelling flux measurements are made with broadband pyranometers (Kipp&Zonen) and with a spectro-photometers which covers the range from 400 to 950 nm with ~1700 channels and ~1nm FWHM. These instruments are mounted on our aircraft door and are above and below the majority of the plane (see Fig. 3). The aircraft GPS (described below) is used to determine when the aircraft is not level and the measurements are not valid. Our cosine response diffuser is constructed with a spectralon diffuser. Tests of the cosine response have shown good results although further tests are needed to cover a range of wavelengths. A trip to the Mauna Loa observatory is planned for this purpose in early July 1999. Absolute irradiance calibration is obtained with a NIST traceable irradiance lamp. Cross calibrations were also recently carried out at the MOBY calibration facility (thanks to Mike Fienholts and Dennis Clark). Good aircraft flux measurements were made on the May 11 and May 29 flights. Wavelength calibration has been completed and absolute calibration for the data sets are now being worked now. A preliminary spectral flux measurement data set is shown in Figure 3.

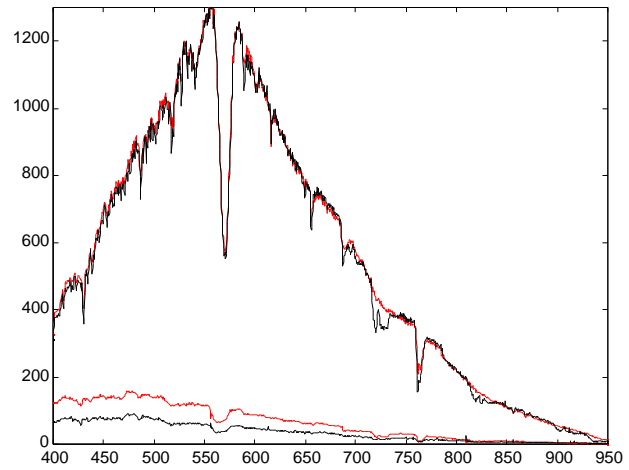
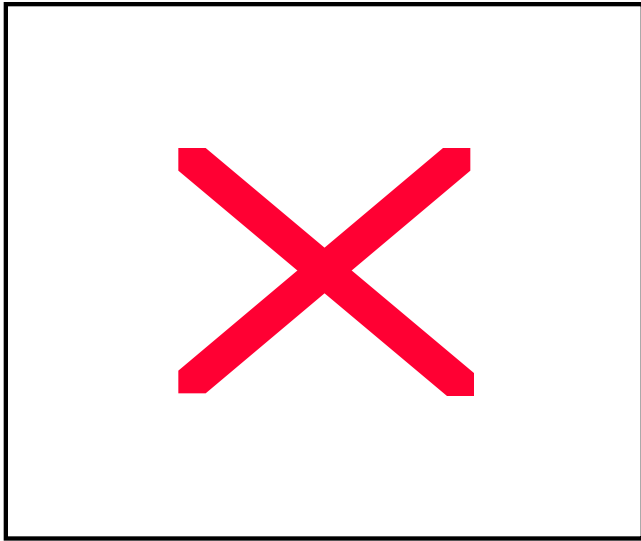


Figure 3. An image of our back two doors. The smaller rear door has upwelling and downwelling irradiance measurements mounted on an aircraft strut. The irradiance measurements include broad band and spectral measurements. The scanning radiometer can also be seen as a cylinder above the letter N. Right panel shows uncalibrated upwelling and downwelling irradiance measurements from a recent flight above the inversion and at the surface. The large dip in the center is due to the change in order sorting filter and is not real.

### **DOWNWARD LOOKING CAMERA**

A scientific grade 14 bit camera (with temperature control) is mounted in the bottom of the plane and views the ocean surface. Four filters are mounted in a filter wheel and are cycled with automatic scaling of the integration time by the computer. Flat field correction is carried out to correct for vignetting effects. Radiometric calibration is obtained using our NIST traceable integrating sphere, which is also compared with the MOBY facility calibration. Unfortunately this system was broken for the May flights but has now been repaired and is ready for future flights.

### **AIRCRAFT DIFFERENTIAL-SURVEY GPS.**

We have installed a differential-survey GPS system on the aircraft to determine the pitch, heading, and position. The four antennae system can determine the aircraft attitude to within less than 0.1 degrees. The position is within ~150 m due to noise in the GPS signal. Using ground based GPS sensors the position can be corrected to within 1 cm for every km away from the ground GPS sensor. For our HOT measurements we expect the final error will be ~150 cm once the ground unit is used (courtesy of Dr. Mike Bevis). The software to carry out these calculations was purchased with the system. GPS data was collected on all three flights during May and are being processed now.

### **7) AEROSOL PHASE FUNCTION MEASUREMENTS**

The aerosol phase function is a critical parameter for many atmospheric radiative problems. Typically MIE theory is used to calculate the phase function although it is known that it is difficult to apply for complex aerosol (i.e. dust, soot and other organic aerosol). Vertical measurements of the aerosol phase function would therefore be very useful in determining the optical properties of dust and sulfate/soot aerosol mixtures. Through support from this NASA EOS cal-val effort and the SIMBIOS effort we have

developed a prototype polar nephelometer to measure the aerosol phase function. This system was tested at Bellows Beach in salt spray aerosol. The aerosol phase function measurements were in close agreement with MIE theory for a salt aerosol model (Porter et al., 1998, Porter and Clarke, 1997). We are currently developing a 2 wavelength version for use on aircraft and in water. The new design uses a pulsed laser with three wavelengths (1064, 532, 355 nm). The detectors have been built and tested for the 532 nm channel. As time and funding permits, we are planning to add the 1064 and 355 nm detectors to the system. The aircraft design for the 532 nm system has been finalized and is now being drawn up for FAA approval before construction. The new system will be mounted on the aircraft door and will measure the angular scatter from 3-177 degrees. The combined phase function can be integrated to obtain the total scattering coefficient. An example of the beach measurements is shown in figure 4.

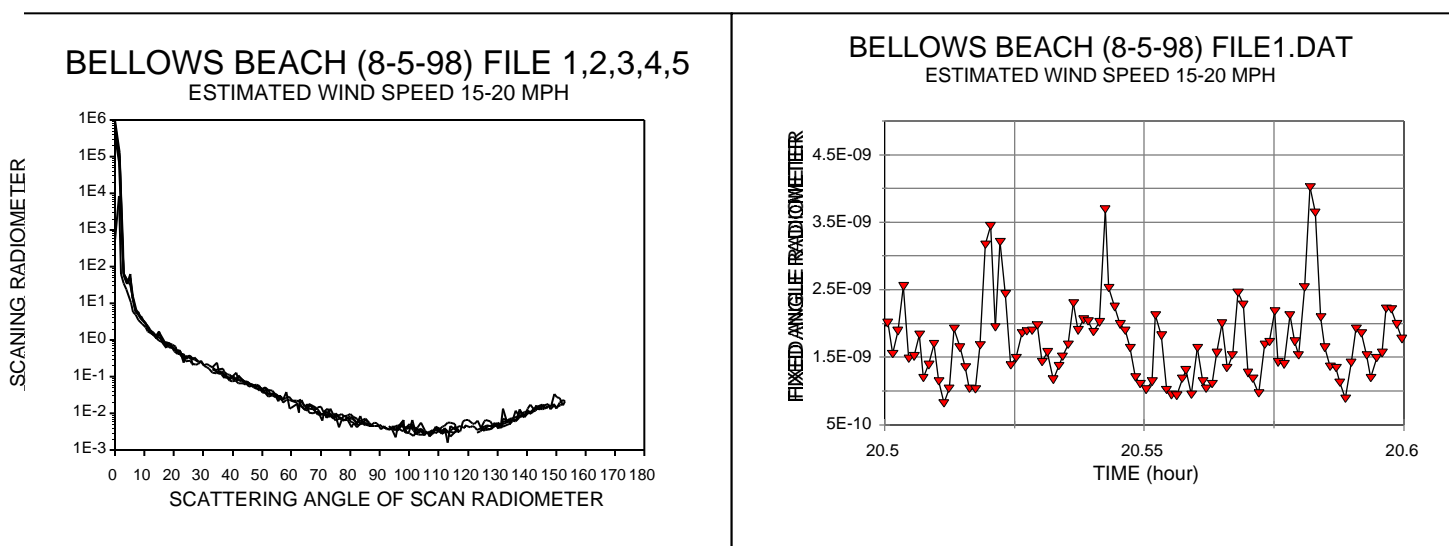


Figure 4. Left panel shows five phase function measurements made at Bellows Beach directly downwind from breaking waves. The phase function is strongly peaked in the forward direction and has an indication of a rainbow at 145 degrees. The right panel shows the aerosol scatter at one angle during the time the aerosol phase function measurements were made. As expected the aerosol scatter is quite variable downwind of breaking waves.

## SKY RADIANCE

Multi-wavelength sky and surface radiance measurements will be made with a custom hand held spectro-photometer. These measurements will help to characterize the aerosol optical properties by measuring the solar aureole and applying aerosol models. The aureole measurements will be made as a function of height to study the vertical distribution of aerosol optical properties. This system is being worked on this month by a technician and is very close to completion. We expect to have it working by late summer.

## IN SITU AEROSOL MEASUREMENTS

The in-situ aerosol measurements since our report last year were interrupted for about 6 months due to two major international field project. We also spent time revising and improving components of our Seneca light aircraft package. This included an upgrade of the laser optical particle counters (OPC) that were originally small portable instruments with low resolution. Our new OPC uses Particle

Measurement Systems (Boulder, CO) optics but with a custom pulse height analysis, computer interface and size resolution of 256 size channels. It provides sizing capability from 0.1 to 5 $\mu$ m. This overlaps the FSSP-300 large particle probe that sizes from about 0.4 to 20 $\mu$ m. The new OPC recently completed flights for measurement of size distributions including vertical profiles above Hawaii (see below) on a larger aircraft. It is presently undergoing post flight calibration before being reconfigured for the Seneca aircraft package.

Sample flight observations below are chosen to illustrate aerosol vertical structure and variability as well as seasonal differences. These include data from the original Seneca aircraft package as well as the new OPC instrument. The Seneca data is shown for two profiles in Fig. 5. The particle condensation nuclei (dominated by small particles below 0.1 $\mu$ m) and light scattering extinction at 530nm (dominated by particle larger than 0.1 $\mu$ m.) are shown versus altitude. These profiles were made at (22.887N, -158.160E-dashed line) and (22.432N, -157.663E) in October of 1998 during a ship intercomparison and satellite overpass. This is also the time of the year when the atmosphere is generally “cleanest” over the North Pacific and near Hawaii. The profiles reveal real differences even though they are only about 50km apart. Near surface light scattering measured in the lowest 300m is virtually identical for both

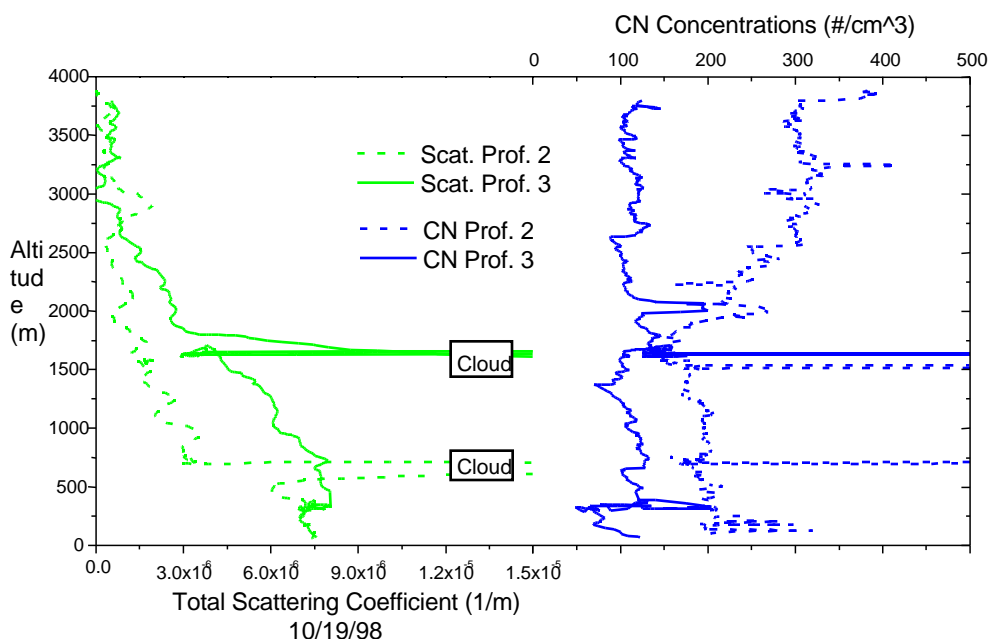


Figure 5. Vertical profiles of aerosol scattering coefficient and condensation nuclei for two flights near Hawaii (shown as dashed and solid).

profiles but differs by a factor of two aloft. Enhanced cloud scatter also appears at several levels. The smaller particle CN differ even more for both profiles but with a tendency for higher concentrations aloft in cleaner air.

Figure 6 shows another profile on October 25 in a similar region where two nephelometers were employed. One nephelometer (magenta) had an impactor size cut to remove particles larger than 1 $\mu$ m generally associated with sea salt. Relative humidity (blue) is also shown and reveals the inversion



above about 2000m. A large difference in scattering is evident below about 300m due to coarse particle sea-salt. At higher altitudes the coarse particle contribute a smaller increase in extinction relative to the submicrometer contribution and total extinction decreases with altitude steadily to our noise level (for this instrument) of  $1 \times 10^{-6} \text{ m}^{-1}$  near 3km. Corrections to ambient extinction will involve allowance for about 25% loss of scattering aerosol in our inlet system and corrections for hygroscopic growth from instrument to ambient RH. Together these will nearly double observed values and suggest a differential optical depth below 3km on the order of 0.03 for this case.

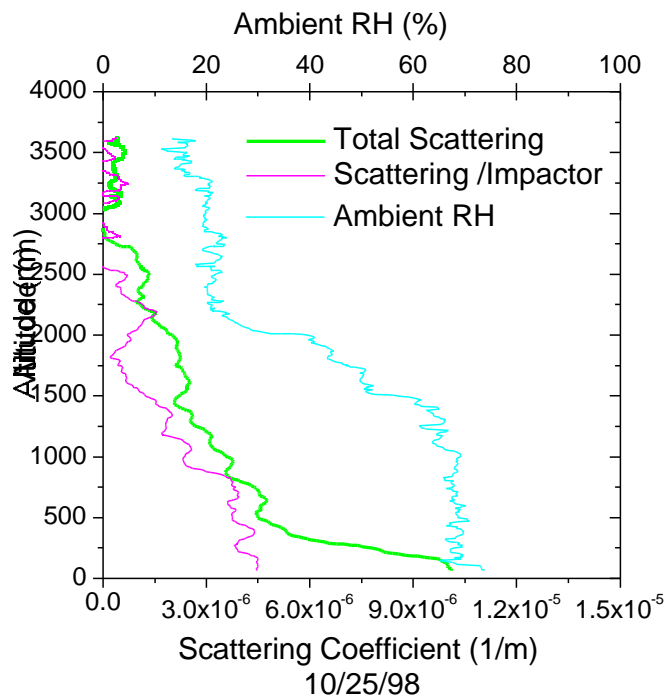


Figure 6. Vertical profile of aerosol scattering coefficient and relative humidity. The magenta line is the aerosol with a impactor cut at  $\sim 1 \mu\text{m}$ .

The October cases above can be contrasted to the springtime conditions when long range transport from Asia introduces aerosol that spreads over the Pacific in the free troposphere. Fig. 7 shows a descent into Hawaii from the South made on April 10, 1999. On the left panel the dry (30%RH) scattering extinction at 450nm(red), 550nm(green) and 750nm (blue) is plotted during the descent and reveals multiple layers with different character. The spread in the wavelength dependence is generally an indication of the steepness of the size distribution between smaller and larger aerosol. We have also indicated our interpretation of the aerosol layers based on the size distributions. The right panel includes other parameters that help interpret the layer behavior. These include CN (magenta), relative humidity (blue) and the fraction of CN remaining after heating to 300C (generally soot, dust or sea-salt). This ratio is low in clean regions dominated by small natural sulfates such as near 4.5km where in spite of the CN number increase the scattering drops to  $2 \times 10^{-6} \text{ m}^{-1}$ . Above and below this layer

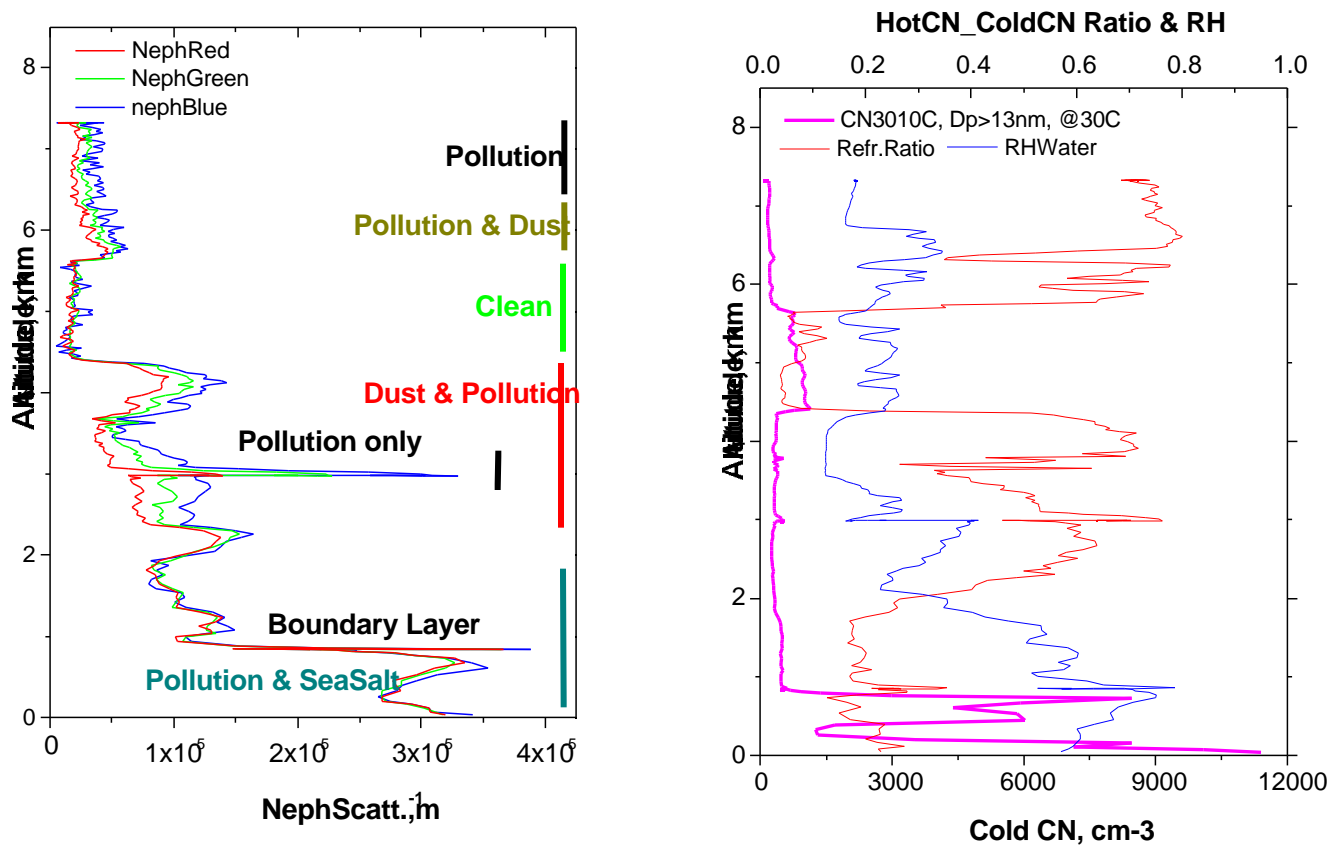


Figure 7. Vertical distribution of aerosol dry scattering coefficient at three wavelengths (left panel) and hot and cold CN and relative humidity (right panel).

are layers of high Hot/Cold CN ratios characteristic of polluted air. Ten day back trajectories (HYSPLIT) for these layers go back to India (upper), China (lower) while the clean layer between remains over the central Pacific.

Composite color coded concentration isopleths are plotted in the figure 8 below for preliminary number size distributions collected by our new OPC during the descent. Concentrations are low in the clean layer but the dark blue shading indicates the presence of some larger dust aerosol. A stronger dust layer is also immediately below the clean layer. However the dust is mixed with a large number of smaller particles with an accumulation mode diameter near 0.17. In spite of the coarse dust the wavelength difference in scattering remains significant. This difference is enhanced near 3km where the layer has little dust and increased accumulation mode pollution with number peak diameters shifted up to 0.25 $\mu m$ . A transition to boundary layer air below 2km has high concentrations of small particles as well as coarse particle sea salt. The latter are responsible for the lack of wavelength dependence in the scatter at these altitudes. Although corrections for RH and proper analysis has not been done we estimate the differential optical depth below 4km for this descent will be near 0.12, or 4 time values for the clean part of the year.



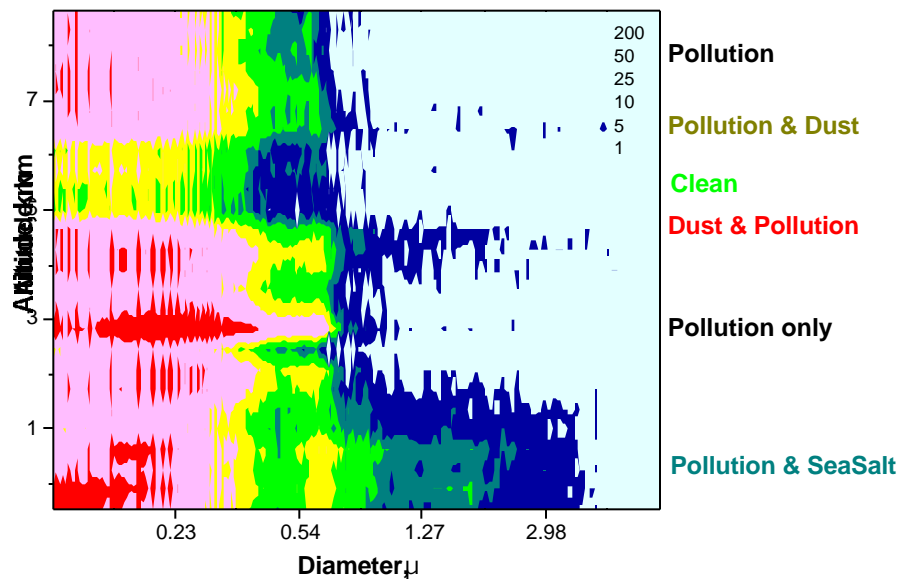


Figure 8. Composite color coded aerosol number distribution isopleths as a function of height.

#### FUTURE PLANS:

Nearly monthly flights will be carried out to the HOT and MOBY sites. Our goal is to link our aircraft measurement closely with in water measurements being made at the MOBY and HOT sites in order to carry out careful ocean color calibration tests. We have a good link with the measurements being made at the HOT site. Although flights will be carried out over the MOBY buoy when no ship measurements are being made, we particularly seek opportunities to fly there when ship cruises are made to the MOBY buoy and we will make it a priority to fly these events.

The MODIS ocean color initialization cruise may take place off Mexico where different ocean color conditions can be found (Dennis Clarke personal communication). Due to the launch delay, a new experiment may be needed for this effort. As these plans become more clear, we are looking into the possibility of carrying out a limited number of flights over the Mexico site using a different Piper Seneca. A suitable aircraft must be found which can be rented and used to carry out a set measurements. Howard Gordon has asked us to bring our polar nephelometer on his experiments and we are working hard to finish the aircraft version so that we can provide this important measurement.

As our instrument development efforts are completed and less time is required in that area, we will be carrying out radiation modeling efforts. The goals are to test for closure between the satellite and aircraft measurements and to test new linearized radiation models which can speed up satellite algorithms for aerosol retrievals. As part of this effort, we are currently finishing a new Monte Carlo radiation model which we will run on a parallel processor at the University of Hawaii (in collaboration with Dr. Torben Nielsen) and we are also running the 6S radiation code (thanks to Eric Vermonte).

#### REFERENCES

Porter, J., Miller, M., Pietras, C.: Ship Based Sun Photometer Measurements Using A MicroTops Sunphotometer. (submitted to SeaWifs Technical Report Series, 1999)

Porter, J., Cooney, T., Motell, C., S.K. Sharma, B.L. Lienert: Coastal Aerosol Phase Function Measurements With A Custom Polar Nephelometer, (Applied Optics, aiming for some time in 1999).